Affective updating ability and stressful events interact to prospectively predict increases in depressive symptoms over time

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Abstract

Previous research has emphasized the critical role of negative cognitions as a vulnerability factor in predicting depressive symptoms. Here, we argue that processes that function to maintain negative cognitions may serve as a catalyst for the development of depressive symptoms in the context of negative circumstances, and we suggest that poor updating of affective information in working memory is one such process. Thus, we posit that under high levels of stress, individuals with poor affective updating are hindered in changing the negative content in working memory associated with stressful events and, therefore, are more likely to experience increased depressive symptoms over time. To examine this hypothesis, we assessed affective updating ability, stress, and depressive symptoms in 200 students who were entering their first year of tertiary education. We assessed levels of depressive symptoms again both four months and one year later. Under high levels of stress, poor affective updating ability was associated with an increase in depressive symptoms at both four months and one year later. These results demonstrate that affective updating ability is an important cognitive vulnerability factor that interacts with stressful events to accelerate the development of depressive symptoms, and underscore the importance of designing early prevention or intervention approaches for individuals with this cognitive vulnerability.

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Introduction

Depression is the fourth leading cause of disability worldwide and is projected to become the second leading cause of disability by 2020 (World Health Organization; Murray & Lopez, 2000). Moreover, half of depressed individuals relapse within two years following recovery from a depressive episode; in fact, relapse rates are as high as 80% among individuals with two or more prior episodes of depression (Burcusa & Iacono, 2007). Investigators have argued that prevention efforts geared towards at-risk individuals are critical in reducing the incidence of depression (Smit, Ederveen, Cujipers, Deeg, & Beekman, 2006). Therefore, understanding risk factors that may contribute to the development of depression is of utmost importance.

Although stress has been implicated as a major cause of the onset of depression, it is clear that not everyone who experiences stress becomes depressed (Kendler, Karkowski, & Prescott, 1999). In this context, researchers have posited that in the face of stressful encounters, certain cognitive vulnerabilities, such as a bias for negative thought content, place individuals at increased risk for depression (Beck, 2008; Abramson, Metalsky, & Alloy, 1989). Recently, however, theorists have suggested that cognitive vulnerabilities for depression are not limited to negative thought *content*; the underlying cognitive *processes* that serve to maintain these negative thoughts may also increase risk for depression. Affective executive functions—the cognitive processes responsible for actively maintaining relevant affective information in working memory—have been proposed as a cognitive vulnerability factor in depression (Gotlib & Joormann, 2010). Specifically, when individuals experience high levels of stress, difficulties in controlling affective information in working memory increase their risk of experiencing depressive symptoms by hindering them from changing, removing, or replacing the negative content in working memory associated with the stressful events.

In studying affective executive functions, researchers have focused primarily on the detrimental consequences of poor cognitive inhibition and poor switching ability (specifically of negative information), demonstrating that such impairments are linked to clinical

depression and a higher level of ruminative responses to negative events and negative mood states (Gotlib & Joormann, 2010; Koster, De Lissnyder, Derakshan, & De Raedt, 2011). This seminal line of work has moved the field forward by drawing attention to the significance of affective executive functions as a cognitive vulnerability factor in depression. It is important to note, however, that affective executive functions involve not only inhibiting irrelevant information from gaining access to working memory or switching mindsets, but also processes that actively modify information in working memory to allow new information to become the focus of attention (e.g., Denkova, Dolcos, & Dolcos, 2014); this process is handled by the executive process of affective updating (Miyake & Friedman, 2012).

In this paper, therefore, we argue that in addition to cognitive inhibition and switching, affective updating is also a key cognitive vulnerability factor in depression. We posit that when individuals experience high levels of stress, impairments in updating affective information in working memory increase their risk for experiencing depressive symptoms.

Affective Executive Functions, Emotion Regulation, and Depression

In the face of stressful events, individuals activate negative thoughts and experience negative emotions. These initial cognitive and emotional responses to stressful encounters can be adaptive; they allow individuals to act immediately or to prepare to take action in response to the immediate threats in their environment (Izard, 2009). Once the event has passed, however, it is equally important for individuals to regulate these initial emotional responses and return them to baseline; this avoids the overload or disruption caused by sustained emotional arousal (Block & Kremen, 1996; Brosschot, Gerin, & Thayer, 2006). Thus, the difficulty is not necessarily with the initial emotional response to the stressful event, but rather with the sustained negative thoughts and emotions that persist even after the stressful event has passed; it is these sustained negative thoughts and emotions that increase individuals' risk of developing depression (Brosschot et al., 2006).

Theorists have proposed that affective executive functions—the ability to control affective information in working memory—may underlie individuals' ability to effectively regulate emotions in the face of stressful events (Gotlib & Joormann, 2010; Koster, et al.,

2011). In understanding affective executive functions, it is important to consider the cognitive architecture in which they work. Working memory is characterized as a limited-capacity system, and executive functions play the key role of controlling the contents of working memory (Baddeley, 1996). There is a variety of internal and external information competing for access to working memory; executive processes are responsible for actively maintaining relevant information in working memory and, thereby, for determining which thoughts are maintained or changed in working memory (Miyake & Friedman, 2012). Therefore, impairments in affective executive functions might lead to affective information being actively maintained in working memory even if it is no longer relevant; this irrelevant information would then affect the type of thoughts on which an individual is currently focusing and, consequently, would influence the emotions experienced.

There is growing evidence that individuals with clinical depression or with elevated levels of depressive symptoms are characterized by impairments in inhibiting and switching of irrelevant negative information (De Lissnyder, Koster, Derakshan, & De Raedt, 2010; Joormann, 2004; Joormann & Gotlib, 2008; Goeleven, De Raedt, Baert, & Koster, 2006; Pe, Vandekerckhove, & Kuppens, 2013; Zetsche & Joormann, 2011). In addition, the failure to inhibit and switch negative information has been linked to more ruminative responses and recurrent negative thoughts (De Lissnyder et al., 2010; De Lissnyder, Koster, & De Raedt, 2012; Joormann & Gotlib, 2008; Joormann, Nee, Berman, Jonides, & Gotlib, 2010; Levens & Gotlib, 2010; Pe et al., 2013). There is also emerging evidence that failing to control negative information places individuals at risk of subsequently experiencing increased ruminative responses and elevated depressive symptoms (Zetsche & Joormann, 2011; De Lissnyder, Koster, Goubert, Onraedt, Vanderhasselt, & De Raedt, 2012). Considered together, these findings demonstrate that impairments in inhibiting and switching of negative information lead individuals to maintain irrelevant negative information in working memory and, as a result, contribute to the experience of sustained negative mood and increase their risk of developing depression.

Affective Updating Ability, Emotion Regulation, and Depression

It is important to note that affective executive control vulnerabilities that increase the risk of developing depressive symptoms may not be limited to poor inhibition and switching of negative content. These vulnerabilities may also involve executive control processes that serve to actively modify the content in working memory. In particular, affective updating—a specific executive function closely related to the construct of working memory (Hofmann, Schmeichel, & Baddeley, 2012; Schmiedek, Hildebrandt, Lovden, Wilhelm, & Lindenberger, 2009; Wilhelm, Hildebrandt, & Oberauer, 2013)—refers to the ability to actively modify the affective contents in working memory to accommodate incoming relevant information (Miyake et al., 2000; Morris & Jones, 1990). For instance, changing perspective about a stressful event (e.g., attending a new school) to make it less stressful requires not only removing previously relevant information from working memory (e.g., "I will not be able to find new friends"), but also moving more recent relevant information into working memory (e.g., "this will be a great opportunity to meet new people"). Difficulties in updating affective information prevent this process from taking place; consequently, it becomes difficult to change the information that is initially activated in working memory, and instead, old irrelevant information is maintained in working memory, which then contributes to sustained or increased negative mood and places individuals at risk of developing depression.

Support for this formulation is provided by the growing number of studies showing that poor updating in working memory is associated with decreased ability to successfully regulate emotions (Hofmann et al., 2012). For instance, individuals who have difficulties updating information in their working memory have been found to report feeling more disgust when they were instructed to appraise a disgusting stimulus in an unemotional manner, and to be less successful at down-regulating their negative emotions when instructed to actively decrease their negative emotions in response to negative pictures (Schmeichel, Volokhov, & Demaree, 2008; McRae, Jacobs, Ray, John, & Gross, 2012). Similarly, individuals with poor affective updating ability were unsuccessful at regulating their emotions in their self-reported daily life experiences. In a seven-day experience sampling study, whereas individuals with

better updating ability experienced a decrease in negative emotions following their reported use of reappraisal as an emotion regulation strategy (i.e., changing perspective about an event), individuals with poor updating ability experienced no change in their negative emotions (Pe, Raes, & Kuppens, 2013). Combined, these findings demonstrate that difficulties in updating affective information in working memory play a significant role in preventing previously relevant information from being replaced with newer, more relevant information. The empirical results render it likely that this impairment contributes to the experience of sustained negative mood and increases risk of developing depression.

Central to our argument is the proposition that a deficit in affective updating ability becomes particularly detrimental in the presence of stressful events because this is the time when individuals' working memory would be particularly centered on negative content. A deficit in updating affective content in working memory would then be expected to create a sustained focus on negative content, hindering individuals from breaking out of this self-defeating focus and leading to an increase in depressive symptoms. Thus, we predicted that experiencing high levels of stress would be associated with increased depressive symptoms in individuals with low affective updating ability, but not in individuals with high affective updating ability.

We tested this formulation empirically in a sample of students who were transitioning to higher (tertiary) education. This transition event is potentially stressful as students must face and adjust to the academic and social challenges brought on by the unfamiliarity of university life (Dyson & Renk, 2006). Using a three-wave longitudinal design, we followed these students for one year as they progressed through their first year of higher education. We measured their ability to update affective information and levels of stress and depressive symptoms at the beginning of the academic year (Wave 1), and then measured their depressive symptoms again two more times: after four months (Wave 2), and after one year (Wave 3).

Based on our postulation that poor updating of affective information is a vulnerability factor for the experience of depressive symptoms, we hypothesize that the association

between affective updating ability and subsequent levels of depression symptoms (after four months and after one year) will be moderated by initial stress levels. Specifically, we predict that under low levels of stress, affective updating ability will not be associated with depressive symptoms. This is consistent with the idea that under low levels of stress, there is less negative content associated with stress in working memory. In this situation, therefore, the ability to update affective information is not critical. In contrast, under high levels of stress, when there is a high proportion of negative content in working memory, poor affective updating ability will be associated with an increase over time in depressive symptoms. Individuals with poor affective updating ability will have difficulties modifying or changing the negative content available in working memory, thereby maintaining negative content in working memory and contributing to an increase in depressive symptoms.

Method

Participants

We aimed to recruit 200 students, representing a broad range of well-being, who were just commencing their first year of tertiary education at a Belgian university or higher education institute. We advertised at secondary schools and tertiary education orientation/information sessions in the Leuven area. Potential participants were directed to a website where they completed the Center for Epidemiologic Studies Depression Scale (CES-D; Radloff, 1977), used for pre-screening. An initial pool of 686 students (65.7% female) completed the online CES-D pre-screening (Range=0–51, *M*=14.64, *SD*=8.63). Using a stratified sampling approach (Ingram & Siegle, 2009), we invited an even number of participants from each quintile of the CES-D range to participate in the study. This procedure was only partially successful: we were able to recruit 180 participants with a relatively broad range of CES-D pre-screening scores (Range = 0–39; *M*=14.41, *SD*=8.41). To achieve our original target, we recruited an additional 22 participants after the study had already begun; therefore, they did not complete the CES-D pre-screening. Importantly, the mean CES-D score for the 22 participants who were not pre-screened (*M*=11.86, *SD*=7.11) did not differ significantly from the mean CES-D score of the remaining 180 participants who completed

the pre-screening (*M*=12.55; *SD*=7.80), *t*(200) =-.393, *p*= .695. For each Wave, participants were reimbursed up to 60€ for completing all measures. Participants were given an additional 60€ at the end of the study if they completed all three waves. Two participants were excluded because they did not comply with the experience sampling protocol (i.e., < 50% response rate in at least one of the waves in the study), leaving a final sample of 200 participants (110 female) at Wave 1, 190 participants (106 female) at Wave 2, and 177 participants (99 female) at Wave 3. Participants ranged in age from 17 to 24 years (*M*=18.32; *SD*=0.96) at the start of the study (see Materials for details on depression scores).

Materials

Assessment of affective updating ability at Wave 1. Participants completed an affective 2-back task to measure updating of affective information (Pe, Koval, Kuppens, 2013, Pe, Raes, et al., 2013). This task measures updating affective information in working memory by requiring participants to continuously change and modify relevant affective information in working memory. Thus, at each trial, participants must remove previously relevant affective information from working memory, which has now become irrelevant (trial *n*-3), encode and identify newer, more relevant affective information in working memory (trial *n*) and match the valence of this new information with relevant, but old affective information in working memory (trial *n*-2).

Forty-seven positive and 49 negative words[1] were selected from the Affective Norms of English Words list (Bradley & Lang, 1999) and translated into Dutch. Words were identified as negative and positive if their valence ratings ranged from 1-4 and 6-9,

[1]Because of the dependency of the trials in the *n*-back, it is challenging to arrange the stimulus set to have exactly the equal number of conditions. For instance, if the word at trial 3, “love” (positive), is changed to “sad” (negative), not only does it change the condition of trial 3, but it also changes the condition of trial 5 (since trial 3 would be the *n*-2 trial). Knowing this difficulty, when we created this version of the affective n-back task, our biggest concern was first, to have an equal number of match and non-match trials. We succeeded in doing this with 44 match trials and 44 non-match trials. Then, we wanted, within these match and non-match trials, to have positive and negative words represented equally: we partially succeeded in doing this and have 22 trials for the positive match condition, 22 trials for the negative match condition, 21 trials for the positive non-match condition, and 23 trials for the negative non-match condition. We tried to keep things relatively equal, but the fact that there were 2 more negative words than positive words in our stimulus set was simply a function of how the task was created and cannot be avoided.

respectively. The stimuli were also matched in word length, number of syllables, and arousal levels (see Pe, Raes, et al., 2013). The task consisted of 24 practice trials (not scored) and 96 actual trials separated into four blocks of 24 trials. The first two trials of every block were not scored, leaving a total of 88 relevant trials for analysis. In each trial, participants viewed a single affective word presented centrally for 500ms followed by a 2500ms inter-trial interval. Participants had to indicate whether the valence of the current word (trial *n*) had the same (match) or different (non-match) valence as the word two trials back (trial *n*-2) by pressing the '1' or '2' key, respectively. Forty-four trials were match trials and 44 were non-match trials. In the match trials, 22 of the 44 trials were positive-valenced stimuli, i.e., trials *n* and *n*-2 were both positive, and the rest were negative-valenced, i.e., trials *n* and *n*-2 were both negative. In the non-match trials, 21 of the 44 trials were positive-valenced stimuli, i.e., trial *n* was positive, but trial *n*-2 was negative, and the rest of the trials used negative-valenced stimuli, i.e., trial *n* was negative, but trial *n*-2 was positive. Non-responses or omissions were scored as errors. To measure participants' ability to update affective information, we calculated the mean accuracy scores across all trials (see also Pe, Koval, et al., 2013; Pe, Raes, et al., 2013) (Kuder-Richardson*20*=.84; *M*=.64, *SD*=.12).

Assessment of stress at Wave 1. We used three different measures of stress to examine whether our results will be consistent across different measures. First, participants completed the Perceived Stress Scale (PSS; Cohen, Kamarck, & Mermelstein, 1983), a 10-item scale that requires participants to indicate the extent to which they found their lives stressful over the past month (e.g., In the past month, how often have you felt nervous or stressed) on a scale from 0 (never) to 4 (very often). The mean PSS score was used as the stress measure on this questionnaire (Cronbach's α = .86; *M*=1.53, *SD*=.60). Second, participants completed the 21-item Depression, Anxiety, Stress Scale (DASS-21; Lovibond & Lovibond, 1995; Dutch version: de Beurs, Van Dyck, Marquenie, & Lange, 2001), which asks participants to indicate the extent to which they have experienced each symptom over the past week using a scale from 0 (never) to 3 (most of the time). The mean of the stress subscale (DASS-S; e.g., I found it hard to calm myself down) was used to assess stress on

this questionnaire (Cronbach's α = .81; *M*=.73, *SD*=.50). Finally, participants participated in an experience sampling methodology study (ESM) described below. At each prompt, participants reported how stressed they were at that moment using a slider anchored at 0 (not at all) and 100 (very much). The mean stress score (ESM-stressed) across all beeps was used as a measure of stress (*M*=23.24, *SD*=11.78). To create a composite measure of stress, we conducted a principal components analysis using the three stress measures described above. Not surprisingly, this produced a one component solution, accounting for 72.88% of the variance. We used the factor score from this procedure for the primary analyses.

Assessment of depressive symptoms at Wave 1, Wave 2 (after 4 months), and Wave 3 (after one year). The study involved three different measures of depressive symptoms, so that we can examine whether the results will be consistent across different measures. First, participants completed the Center for Epidemiological Studies Depression scale (CES-D; Radloff, 1977), in which they rated how frequently they experienced a range of depressive symptoms (e.g., "I had crying spells") over the past week on a four-point scale from 0 (rarely or none of the time) to 3 (most or all of the time). The mean of all the CES-D items was used to measure depression (Wave 1: Cronbach's α=.90, *M*=.63, *SD*=.39; Wave 2: Cronbach's α =.92, *M*=.58, *SD*=.44; Wave 3: Cronbach's α =.88, *M*=.48, *SD*=.35). Second, the mean of the depression-subscale (DASS-D; e.g., I couldn't seem to experience any positive feeling at all) from the DASS-21 described above was computed (Wave 1: Cronbach's α=.81, *M*=.46, *SD*=.42; Wave 2: Cronbach's α=.86, *M*=.63, *SD*=.39; Wave 3: Cronbach's α=.82, *M*=.33, *SD*=.37). Finally, participants completed the ESM protocol described below. At each prompt, participants reported how depressed they were at that moment using a slider anchored at 0 (not at all) and 100 (very much). The mean depression score (ESM-depressed) across all beeps for each wave was used as a measure of depression (van Rijsbergen, et al., 2014) (Wave 1: *M*=12.74, *SD*=9.88; Wave 2: *M*=11.66, *SD*=9.52; Wave 3: *M*=10.65, *SD*=9.09).

To create a composite measure of depressive symptoms, we conducted a principal components analysis using the three depression measures described above. We did this analysis three times, one for each Wave. Each of these analyses produced a one component solution, accounting for 65.03% of the variance at Wave 1, 67.69% of the variance at Wave 2, and 64.48% of the variance at Wave 3. We used the component scores from this procedure for all primary analyses.

Procedure

At the beginning of each Wave, participants were invited to the lab individually. During the first session, participants completed the CES-D and the affective updating task, among other questionnaires, on a desktop computer. Next, participants received a Motorola Defy plus Smartphone, which was programmed to beep 10 times each day between 10 a.m. and 10 p.m. for 7 days according to a stratified random interval scheme (each period was divided into ten equal intervals and one random beep was programmed in each interval). The average interval between two consecutive beeps was 71.7 min (SD = 29.2) for Wave 1, 71.9 min (SD = 29.5) for Wave 2, and 72.0 min (SD = 29.5) for Wave 3. Overall, participants demonstrated good compliance: they responded to 87.27% (*SD*=9.05%), 87.87% (SD=8.98%), and 88.35% (SD=8.69%) of all the programmed beeps at Waves 1, 2, and 3, respectively. After the ESM week, participants returned to the lab to return their smartphones and completed a series of additional questionnaires, including the DASS-21 and the PSS, and were paid for their participation. After the last session in Wave 3, they were debriefed.

Statistical analysis

To test our central hypothesis, we conducted regression models with Wave 1 affective updating ability (standardized), Wave 1 level of stress, and their interaction as predictors, and depressive symptoms at Wave 2 (at four months) or Wave 3 (at one year) as the criterion variable. We included Wave 1 depressive symptoms as a predictor in the regression to account for the initial levels of depressive symptoms, and model change in depressive symptoms over time. To disentangle significant interaction effects (Preacher,

Curran, & Bauer, 2006), follow-up simple slope analyses were conducted in order to better understand the nature of the association between affective updating and change in depressive symptoms over time for individuals with average, higher (1*SD* above the average), and lower (1*SD* below the average) levels of stress.

Results

Correlations of the constructs assessed in this study are presented in Table 1. Results for the regression analyses are presented in Table 2.

Depressive Symptoms after Four Months

Both composite stress (marginally significant) and affective updating ability predicted change in composite depressive symptoms at four months, such that higher initial stress and poorer affective updating ability were associated with increased depressive symptoms. These main effects were qualified, however, by the predicted significant interaction between stress and updating of affective information. Simple slope analysis revealed that under low levels of stress, affective updating ability was not associated with change in depressive symptoms after four months (adjusting for depression levels at Wave 1), β=.03, *SE*=.08, *t*=.36, *p*=.72, 95%CI[-.12, .18]. Under average and high levels of stress, however, affective updating ability was negatively associated with change in depressive symptoms after four months (average stress: β=-.13, *SE*=.06, *t*=-2.39, *p*=.02, 95%CI[-.24, -.02]; high stress: β=-.30, *SE*=.07, *t*=-4.51, *p*<.01, 95%CI[-.43, -.17]). That is, low affective updating ability was associated with higher levels of depressive symptoms after four months (see Figure 1, left panel). The model combining the main effect of affective updating ability, and its interaction with stress explained ~6-7% of the variance in depressive symptoms (in addition to the variance explained by initial levels of depressive symptoms and stress) after four months[2].

[2]We also conducted simple slope analyses in which affective updating was the moderator of the relation between stress and change in depressive symptoms after four months. Results indicated that for individuals with low affective updating ability, stress was positively associated with change in depressive symptoms (β=.31, *SE*=.09, *t*=3.33, *p*<.01, 95%CI[.13, .50]); for individuals with average affective updating ability, stress was marginally positively associated with change in depressive symptoms (β=.15, *SE*=.08, *t*=1.82, *p*=.07, 95%CI[-.01, .31]); and for individuals with high affective updating ability, stress was not associated with change in depressive symptoms (β=-.01, *SE*=.09, *t*=-.13, *p*=.90, 95%CI[-.20, .17]).

Depressive Symptoms after One Year

Affective updating ability, but not level of stress, was marginally inversely associated with change in depressive symptoms after one year, adjusting for depression levels at Wave 1. Similar to the analysis with Wave 2, the interaction between stress and updating of affective information was significant (see Table 2). Simple slope analyses were conducted to examine these interaction effects. Similar to the findings described above, under low levels of stress, affective updating ability was not associated with change in depressive symptoms after one year (adjusting for depressive symptoms at Wave 1), β=.06, *SE*=.08, *t*=.68, *p*=.50, 95%CI[-.11, .22]. Under average levels of stress, affective updating ability was negatively associated (although marginally significant) with change in depressive symptoms after one year, β=-.11, *SE*=.06, *t*=-1.78, *p*=.08, 95%CI[-.31, .10]. Under high levels of stress, however, affective updating ability was again negatively associated with change in depressive symptoms one year later, β=-.27, *SE*=.07, *t*=-3.90, *p*<.01, 95%CI[-.41, -.14] (see Figure 1, right panel). The model including the main effect of affective updating ability, and its interaction with stress explained ~6% of the variance in depressive symptoms (in addition to the variance explained by initial levels of depressive symptoms and stress) after one year. Together, these results demonstrate that, as we hypothesized, under high levels of stress, low affective updating ability predicted an increase in depressive symptoms after four months and after one year.[3]

Secondary Analyses

We also conducted the same set of regression analyses with the separate observed variables (rather than the factor scores), with largely similar results. We briefly report them here. Generally, the interaction between PSS and affective updating predicted the various depression measures at four months (CESD: β=-.05, *SE*=.03, *t*=-1.85, *p*=.07, 95%CI[-.09,

[3]We also conducted simple slope analyses in which affective updating was the moderator of the relation between stress and change in depressive symptoms after one year. Results indicated that for individuals with low affective updating ability, stress was positively associated with change in depressive symptoms (β=.27, *SE*=.11, *t*=2.60, *p*=.01, 95%CI[.07, .48]); for individuals with average and high affective updating ability, stress was not associated with change in depressive symptoms (average updating: β=.11, *SE*=.09, *t*=1.18, *p*=.24, 95%CI[-.07, .29]; high updating: β=-.05, *SE*=.10, *t*=-.53, *p*=.60, 95%CI[-.26, .15]).

.00], ΔR^2=.01; DASS-D: β=-.08, *SE*=.03, *t*=-3.00, *p*<.01, 95%CI[-.13, -.03], ΔR^2=.03; ESM-depressed: β=-1.04, *SE*=.44, *t*=-2.38, *p*=.02, 95%CI[-1.91, -.18], ΔR^2=.02), and at one year (CESD: β=-.06, *SE*=.02, *t*=-2.98, *p*<.01, 95%CI[-.10, -.02], ΔR^2=.04; DASS-D: β=-.07, *SE*=.02, *t*=-3.46, *p*<.01, 95%CI[-.11, -.03], ΔR^2=.05; ESM-depressed: β=-.52, *SE*=.46, *t*=-1.14, *p*=.26, 95%CI[-1.42, .38], ΔR^2=.00); the interaction between DASS-S and affective updating predicted the various depression measures at four months (CESD: β=-.05, *SE*=.02, *t*=-1.90, *p*=.06, 95%CI[-.09, .00], ΔR^2=.01; DASS-D: β=-.09, *SE*=.03, *t*=-3.55, *p*<.01, 95%CI[-.14, -.04], ΔR^2=.05; ESM-depressed: β=-1.05, *SE*=.42, *t*=-2.50, *p*=.01, 95%CI[-1.87, -.22], ΔR^2=.02), and at one year (CESD: β=-.04, *SE*=.02, *t*=-2.11, *p*=.04, 95%CI[-.08, -.00], ΔR^2=.02; DASS-D: β=-.06, *SE*=.02, *t*=-3.01, *p*<.01, 95%CI[-.10, -.02], ΔR^2=.04; ESM-depressed: β=-.38, *SE*=.44, *t*=-.85, *p*=.40, 95%CI[-1.24, .49], ΔR^2=.00); the interaction between ESM-stressed and affective updating also predicted the various depression measures at four months (CESD: β=-.04, *SE*=.02, *t*=-1.82, *p*=.07, 95%CI[-.09, .00], ΔR^2=.01; DASS-D: β=-.09, *SE*=.03, *t*=-3.48, p<.01, 95%CI[-.14, -.04], ΔR^2=.05 ; ESM-depressed: β=-1.15, *SE*=.43, *t*=-2.65, p<.01, 95%CI[-2.00, -.29], ΔR^2=.02), and at one year (CESD: β=-.05, *SE*=.02, *t*=-2.36, *p*=.02, 95%CI[-.09, -.01], ΔR^2=.02; DASS-D: β=-.06, *SE*=.02, *t*=-3.10, *p*<.01, 95%CI[-.11, -.02], ΔR^2=.04; ESM-depressed: β=-.75, *SE*=.44, *t*=-1.69, *p*=.09, 95%CI[-1.62, .13], ΔR^2=.01)[4].

We also collected measures of affective updating ability at Waves 2 and 3 to measure its test-retest reliability: the correlation between affective updating at Wave 1 and Wave 2 (after a four-month interval) was at .70; the correlation between affective updating at Wave 1 and Wave 3 (after a 12-month interval) was at .66; the correlation between affective updating at Wave 2 and Wave 3 (after an eight-month interval) was at .74. These values demonstrate good test-retest reliability, and are comparable to the test-retest reliability of other measures of working memory (e.g., see Hockey & Geffen, 2004; Klein & Fiss, 1999). We also conducted alternative analyses in which we created a component score of affective

[4] ΔR^2 was computed for the variance explained by the interaction between the specific stress measure and emotional updating ability (in addition to variance explained by initial depressive symptoms and main effects of stress and emotional updating ability).

updating ability by conducting a principal components analysis and using scores from all three Waves. We used this component score as the affective updating ability predictor instead of the affective updating ability score at Wave 1. Results were similar to our main analyses: there was a significant interaction between stress and updating ability to predict change in depressive symptoms both after four months (β=-.17, *SE*=.06, *t*=-3.02, *p*<.01, 95%CI[-.28, -.06]) and after one year (β=-.21, *SE*=.06, *t*=-3.67, *p*<.01, 95%CI[-.33, -.10]).

Discussion

We found empirical support for our hypothesis that the interaction of affective updating ability and stress predicts change in levels of depressive symptoms. Specifically, we found that under high levels of stress, affective updating ability was negatively associated with depressive symptoms both four months and one year after entering university. This was not the case for participants under low levels of stress, whose affective updating ability was not associated with depressive symptoms at either the four-month or one-year follow-up assessment. These findings suggest that under high levels of stress, deficits in updating of affective information significantly predict an increase in depressive symptoms.

This study contributes to the literature in several ways. First, research examining the possibility that affective executive functions are a risk factor of depression has focused most often on the executive process of cognitive inhibition and switching. Indeed, previous research has demonstrated that poor inhibition and switching of negative information predicts increased depressive symptoms and more ruminative responses over time (Zetsche & Joormann, 2011; De Lissnyder, Koster et al., 2012b). Importantly, however, affective executive functions are not limited to only cognitive inhibition and switching (Miyake & Friedman, 2012). The current study examined the possibility that other affective executive processes, such as poor affective updating ability, are also risk factors for depression. In this study, we have indeed shown this to be the case: we demonstrated that under high levels of stress, difficulties in updating affective information in working memory predicted increased depressive symptoms after six months and one year.

Second, previous research has already implicated deficits in affective updating ability as a characteristic of individuals with clinical depression (Levens & Gotlib, 2010). Whether this deficit occurs before or after being diagnosed with clinical depression, however, has not been examined. The present study addresses this question by demonstrating that healthy individuals are characterized by varying levels of affective updating ability, and that low levels of affective updating, when combined with high levels of stress, increases their depressive symptoms.

Third, the present study was designed to examine an event that is considered relatively stressful for all the participants, and then to track longitudinally their change in depressive symptoms. In this context, we recruited as participants students who were about to enter their first year of tertiary education—a period that is relatively stressful for most students (Gall, Evans, & Bellarose, 2000). In testing the proposition that affective updating ability is an important cognitive vulnerability factor in the development of depressive symptoms, this methodology allowed us to examine whether poor affective updating ability plays a significant role in exacerbating the effects of stress on the increase of depressive symptoms over time.

The fourth contribution of this study is that we used both retrospective questionnaires and experience sampling methodology to measure stress and depressive symptoms. This methodology is important because results from the experience sampling portion offer insight about experiences in real time, which is distinct from trait questionnaires, in which participants must rely on their memory (Kahneman & Kreuger, 2006). Moreover, although the trait questionnaires were measured retrospectively, allowing for the possibility that feelings of stress influenced performance on the affective n-back task, the experience sampling paradigm was implemented *after* the n-back task was administered. This prevents the stress measure (in the experience sampling) to influence the affective n-back task. The fact that the results remained consistent across these different methodologies and various measures gives us greater confidence in our findings: individuals with poor affective updating ability tend to be more vulnerable to the detrimental effects of stress, thereby

putting them at risk of experiencing increased depressive symptoms in the future.

Finally, conceptualizing poor affective updating ability as a cognitive vulnerability factor for depression suggests that early interventions for individuals with poor affective updating ability will be fruitful in preventing the development of depression when they are faced with life stressors. Based on the present findings, there are at least three ways of intervening in this manner. First, we can directly improve individuals' affective updating ability by training their working memory with emotional material (Denkova et al., 2014; Schweizer, Grahn, Hampshire, Mobbs, & Dalgleish, 2013; Siegle, Price, Jones, Ghinassi, Painter, & Thase, 2014). With the current debate regarding the effectiveness of these training paradigms, however, it is clear that more research is needed to improve and test whether these programs indeed improve working memory (Shipstead, Redick & Engle, 2012). Second, we can indirectly improve individuals' affective updating ability through other interventions, such as expressive writing (Klein & Boals, 2001). Indeed, previous research (Klein and Boals, 2001; Yogo & Fujihara, 2008) has demonstrated that letting students write about their worries appears to increase their working memory capacity, presumably because expressive writing reduces intrusive thinking about a stressor, which then frees working memory resources. Finally, rather than changing individuals' affective updating ability, we can give individuals with low affective updating ability resources about how they might cope with life stressors despite having this deficit.

Two features of this work limit the conclusions that we can draw about poor affective updating ability being a risk factor for depression. First, the sample in this study is composed of healthy individuals entering their tertiary education. Although this may be seen as strength given that we can detect changes in depressive symptoms over time before the onset of clinical depression, we cannot generalize these findings to predicting a clinical diagnosis. Indeed, examining whether clinically depressed individuals might differ from healthy controls in their affective updating ability would be a worthwhile endeavor, as it would increase our understanding of the role of affective updating ability in the development of clinically significant depression. Based on our current findings and on previous research (Harvey, et

al. 2004; Levens & Gotlib, 2010; Rose & Ebmeier, 2006), we hypothesize that clinically depressed individuals would have poorer affective updating ability than would healthy controls.

Second, the interaction of affective updating and stress yielded an additional 4% explained variance in future depressive symptoms. One might argue that this effect size is not sufficiently important to be considered as a risk factor for depression. We contend that this effect is indeed meaningful for two reasons. First, in examining the measures that were used in this study, we should note that while our measure of affective updating was a computer-based task, our measures of depressive symptoms and stress were based on self-report. It is striking that responding “match” or “non-match” to a series of words on a computer in the lab is associated with self-reported stress and depressive symptoms. Furthermore, these findings were consistent across different measures, across different methodologies, and across time. Second, given that behaviors in general tend to be relatively stable over time, the amount of change in levels of outcome in a longitudinal study tends to be small (Adachi & Willoughby, 2014). Nevertheless, small effects in on-going processes can have a large impact in the longer-term (Prentice & Miller, 1992; Adachi & Willoughby, 2014). For instance, low affective updating ability may have a small predictive effect on changes in levels of depressive symptoms after 4 months and one year. Over several years, however, these effects may become additive, such that after encountering multiple stressful situations, having poor affective updating ability may have a significant cumulative impact on changes in depressive symptoms, which may then lead to clinical depression.

In conclusion, our results emphasize the important role of affective updating ability in predicting the relation between stress and the development of depressive symptoms. Recognizing the vulnerability for depression brought about by poor affective updating ability highlights the potential importance of early intervention programs for individuals with this cognitive vulnerability.

Conflict of interest

None.

Ethical standards

The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national and institutional committees on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008.

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Table 1. Correlations of the Variables Used in the Main Analysis.

		1	2	3	4
	Wave 1 (*N*=200)				
1	Affective updating (Wave 1)				
2	Stress (W1)	-.19**			
3	Depressive Symptoms (Wave 1)	-.12	.76**		
4	Depressive Symptoms (Wave 2)	-.27**	.55**	.63**	
5	Depressive Symptoms (Wave 3)	-.24**	.51**	.59**	.67**

Note: Stress and depressive symptoms are component scores.
Wave 1: *N*=200; Wave 2: *N*=189 (one participant failed to complete the DASS-21 questionnaire); Wave 3: *N*=177.
**p <.01, *p<.05

Table 2. Stepwise Regression Analyses with Initial Stress (Wave 1), Affective updating Ability (Wave 1) and Their Interaction Predicting Depressive Symptoms at Four Months (Wave 2) and at One Year (Wave 3), while Adjusting for Initial Levels of Depressive Symptoms (Wave 1).

	Criterion: Depressive symptoms at Wave 2 (at four months)					Criterion: Depressive symptoms at Wave 3 (at one year)				
Predictors Wave 1	*Coef*	*SE*	*t*	*p*	95% [CI]	*Coef*	*SE*	*t*	*p*	95% [CI]
Model 1										
Intercept	.00	.06	.01	.99	-.11, .11	-.02	.06	-.24	.81	-.14, .11
Depressive symptoms	.62	.06	10.94	<.01	.51, .73	.57	.06	9.54	<.01	.45, .69
ΔR^2	.39			<.01		.34			<.01	
Model 2										
Intercept	-.00	.06	-.02	.98	-.11, .11	-.02	.06	-.35	.72	-.14, .10
Depressive symptoms	.48	.09	5.58	<.01	.31, .65	.47	.09	5.04	<.01	.28, .65
Stress	.19	.09	2.18	.03	.02, .36	.14	.10	1.46	.15	-.05, .33
ΔR^2	.02			.03		.01			.15	
Model 3										
Intercept	.00	.06	.00	.99	-.11, .11	-.02	.06	-.31	.75	-.14, .10
Depressive symptoms	.48	.08	5.75	<.01	.32, .65	.47	.09	5.20	<.01	.29, .65
Stress	.15	.09	1.76	.08	-.02, .32	.10	.10	1.06	.29	-.09, .29
Aff Upd	-.17	.06	-2.94	<.01	-.28, -.05	-.15	.06	-2.40	.02	-.27, -.03
ΔR^2	.03			<.01		.02			.02	
Model 4										
Intercept	-.03	.05	-0.61	.54	-.14, .07	-.05	.06	-.91	.37	-.17, .06
Depressive symptoms	.47	.08	5.73	<.01	.31, .63	.45	.09	5.09	<.01	.28, .63
Stress	.15	.08	1.83	.07	-.01, .31	.11	.09	1.18	.24	-.07, .29
Aff Upd	-.14	.06	-2.39	.02	-.25, -.02	-.11	.06	-1.78	.08	-.23, .01
Aff Upd x Stress	-.16	.05	-3.62	<.01	-.25, -.07	-.16	.05	-3.43	<.01	-.26, -.07
ΔR^2	.04			<.01		.04			<.01	

Note: Aff Upd = Affective updating task.

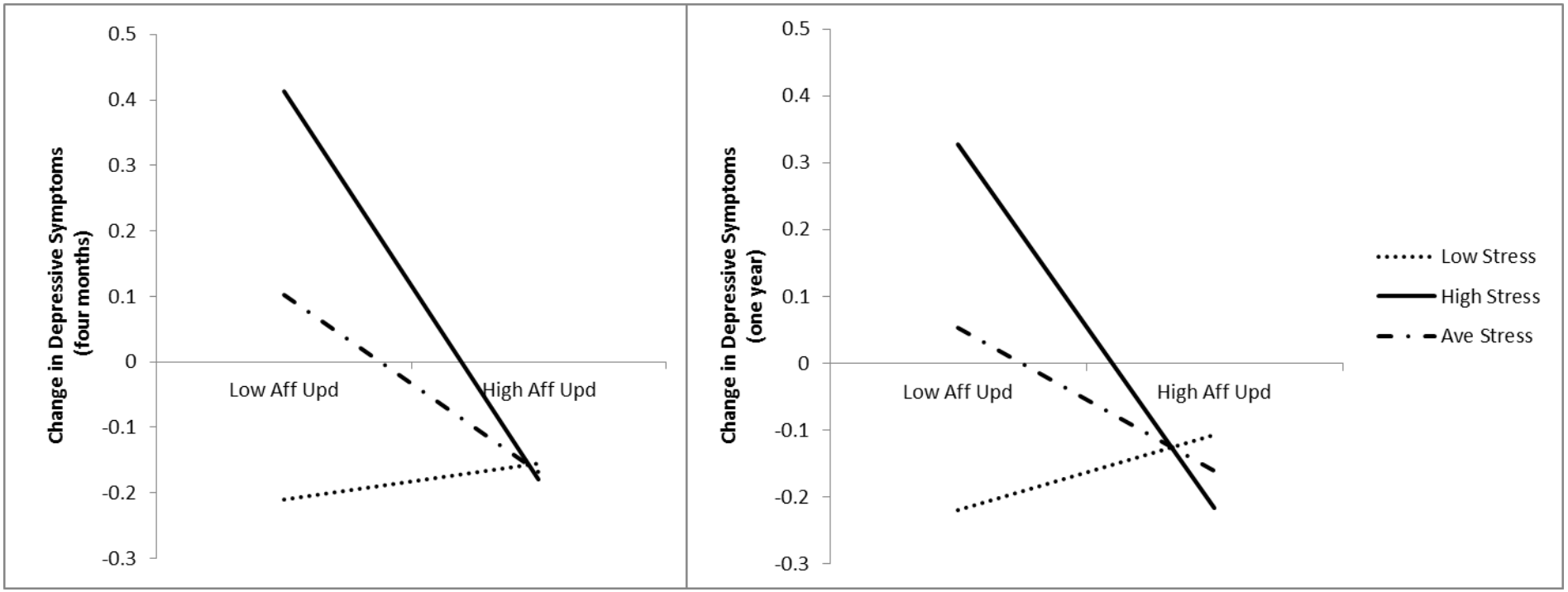

Figure 1. Graphs show relationships between affective updating ability and depressive symptoms at four months (Wave 2; left panel) and at one year (Wave 3; right panel) for individuals who experienced high (1*SD* above the mean; bold line), average (mean level; dashed and dotted line) and low (1*SD* below the mean; dotted lines) stress levels at the start of the academic year (Wave 1). All figures were estimated while adjusting for levels of depressive symptoms at Wave 1.